Life: Origin and Evolution on Earth — How Can We Escape?

N94-19217

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ABSTRACT

Exploitation of gene regulation rather than the creation of new genes has been predominantly responsible for the evolutionary advances in animals and plants that are widely recognized today. Until very recently it was not possible to examine life in the absence of gravity. We can now imagine forms of life in the universe adapting to circumstances different from those found on Earth. Our own life forms would surely become different in time if they were transferred to other planets with different conditions, including much lower or higher gravity.

Life arose on Earth nearly four billion years ago as membrane-contained biochemical and biophysical systems that were isolated from each other and protected from the environment. These systems could enlarge, subdivide, and reproduce as individual organisms. Organic and inorganic molecules were selectively absorbed and processed, and some molecules were then excreted (cf. Schopf, 1983). Thus, a form of biological replication — crude and erratic at first — slowly evolved, stabilized, and began to exhibit characteristics appropriate for the survival of the fittest. It took a billion years or more for this system to evolve beyond a bacterium-like cell stage. The basic biochemical patterns and the mechanisms for replicating the biochemical architecture with integrity must have evolved very slowly during an additional two billion years. Perhaps another 700 million years passed during the evolution of multicellular organisms, which takes us to the middle of the Cambrian era of evolutionary development (cf. Avers, 1989). Then, within the next 500 million years, all of the contemporary divisions of plant and animal phyla developed. Mammals and higher plants have been around for about 200 million years, since the Triassic age of the Mesozoic era, but in the case of the mammals at least, these organisms were primitive and very small and not numerous for the next 140 million years. Only since the dinosaurs disappeared at the beginning of the Cretaceous era have mammals and flowering plants undergone an explosive evolution. The first primates go back about 60 million years. Contemporary humans shared a common ancestor with our close relatives, the great apes, about 10 millions years ago, and the ancestors of contemporary human beings, *Homo sapiens*, have been recognizable for perhaps the last two or three hundred thousand years. Modern humans biologically indistinguishable from ourselves may go back only 40 or 50 thousand years. Thus, we are very late comers to Earth.

The extraordinarily rapid development that we seem to see in the formation of the most highly evolved organisms today in terms of their size, mobility, and capacity to dominate the environment reflects perhaps an accelerating rate of diversification of life forms. This diversity is based upon a reassortment and rearrangement of basically the same building blocks (cells) — building blocks that were created by the billions of years of early evolution (cf. Briggs and Crowther, 1990). Of course, human cultural, scientific, and technological evolution that gave rise to contemporary civilizations began just a few thousand years ago, and most developments have occurred within the last few hundred years. This recitation of freshman biology has been made to emphasize that the exploitation of gene regulation rather than the creation of new genes is primarily responsible for the evolutionary advances in metaphytes and metazoans — i.e., multicellular plants and animals. In animals especially, but plants as well, the precise movement and/or associations of cells and their parts, all sensitive to gravity (more precisely, in plants both meristematic and non-meristematic regions may be graviresponsive), are critical for recent evolutionary developments.

All of this evolution, of course, proceeded with gravity as an ever present and constant aspect of the environment. Biologists have investigated many of the specific mechanisms of evolution, as well as the basic biochemical and biophysical nature of life itself, but we have given practically no attention to the role that gravity has played and is playing in the structure and functioning of contemporary organisms (cf. Stebbins, 1982; Avers, 1989). The explanation is

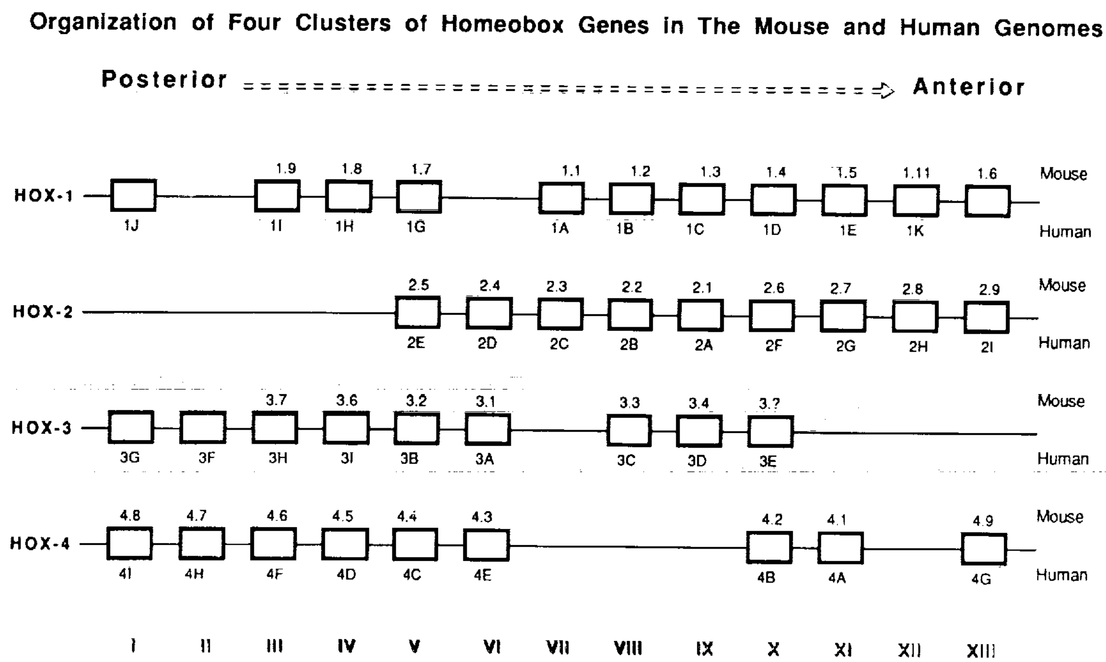

Figure 1. **Distribution along chromosomes of homologous genes in mouse and humans that contain homeoboxes. These genes are activated in the embryo in a temporal and spatial sequence that corresponds to the linear position of the genes along the chromosome. The homology of the homeobox sequences among many taxa has been highly conserved throughout evolution. Diagram redrawn from Murtha et al., 1991.**

simple, of course. Until very recently, it was not possible to examine life in the absence of gravity. Now we can do so with the space vehicles and stations and with our ability to engage in space travel (cf. Krikorian and Levine, 1991).

Life itself has made the Earth a very different place from what it was before life evolved. There is a film of living material covering virtually all of the land surface of the Earth and, of course, also in the water that covers most of the Earth's surface. The gaseous atmosphere has been changed by the activity of life, and thus has changed the environment with consequent effects on the further evolution of organisms. Life continuously creates a changing environment and then responds to the changes by further evolution (cf. Briggs and Crowther, 1990). We have never escaped from gravity except momentarily and then only in recent years. It is possible to imagine many other forms of life in the universe evolving and adapting to quite different circumstances from those we find on Earth, and our own life forms on Earth would surely become different if they were transferred to other planets with different physical conditions, including much lower or much higher gravity.

The current importance of understanding the role of gravity in our own evolution and development stems primarily from the fact that we plan to send explorers to the moon and to Mars and perhaps elsewhere and to take other forms of life with us (cf. e.g., Robbins Committee Report, 1988). The consequences for the structure, physiology, and development of ourselves and other organisms will surely be profound, and it behooves us to understand the significance of gravity in determining our own basic biological nature before we meet these extraterrestrial challenges. At the most basic level of life, the individual cell, we find a vast array of molecules, of cell organelles, and of various elaborate structures that collectively make possible the biochemical activities that keep the cell alive, developing, and reproducing (cf. Alberts et al., 1989).

Recently, we have come to recognize the organization of specific groups of genes containing sequences (homeoboxes) that seem to specify in time and place the development of the organism (cf. e.g., Murtha et al., 1991). In mice and humans, both species have been extensively investigated: four different clusters of homeoboxes have been identified, each on a different chromosome. Within each of these clusters, there are about ten genes distributed along the chromosome in a precise order that is the same for mice and humans. This physical arrange-

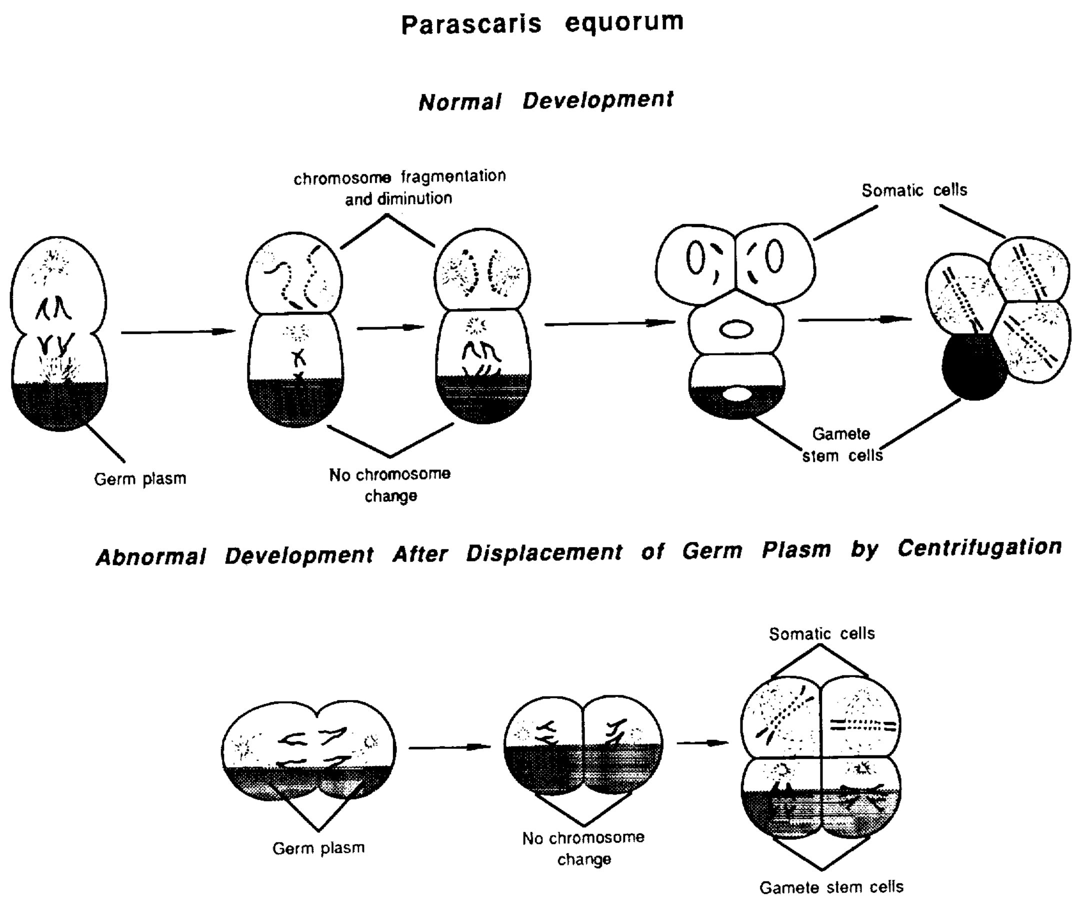

Figure 2. Diagram showing results of centrifugal displacement of germinal plasm in *Parascaris [Ascaris megalocephala]*. Presence of germinal plasm in a cell prevents chromosomal diminution and fragmentation of large chromosomes into many small chromosomes. The presence of intact large chromosomes are essential for germ cell development. Cells with reduced chromosomal content become somatic cells. After Boveri, 1910.

ment — the anterior-posterior sequence — corresponds to the time of activation of these genes during the course of early development (Figure 1). Similar patterns of homeobox organization have been discovered in a wide variety of organisms stretching all the way back to the most primitive multicellular organisms. The fact that these genes have been extraordinarily well conserved during the course of evolution indicates that they must have a fundamental role in determining the structure of organisms. All of the evidence we have so far indicates that they do play such roles in developing the basic morphology, very likely by affecting cell associations and relative rates of multiplication that could define the axial and other structures of the developing organism. Clearly, these genes could not be abnormally activated or inactivated without drastic effects on the development of the organism. Progressive slight changes, in accord with what we might expect in evolution, could of course lead to the variety of morphologies that we see in different organisms. Obviously, however, the slightest perturbation in the activation of these genes during the course of development would have profound consequences. Thus, the role of gravity in perturbing the program of activation of these homeobox genes must be understood in detail if we are to safely reproduce in space. Molecules and organelles can be moved within the cell by centrifugation and, therefore, must respond to gravitational forces exerted on the cell; such redistributions of components within a cell could prove fatal or at least could change the development of embryos. The temporary redistribution of cell contents by centrifugation can frequently be overcome and the original state of the cell restored. Many forces are involved in molecular traffic to move and orient molecules and organelles within the cell. Gravity is certainly one of them (cf. Halstead et al., 1991). How the cell manages without gravity and how it changes in the absence of gravity are basic questions that only prolonged life on a space station will enable us to answer (cf. Souza and Halstead, 1985; Asashima and Malacinski, 1990).

We know from the experience acquired so far on space vehicles and stations, our own and those of the Soviet astronauts (cf. Garshnek, 1988), that profound deleterious physiological effects do occur and jeopardize the functional capacity and even the survival of human beings. To counteract or circumvent these effects, we need to know more of the basic biochemistry and biophysics of the cell and of the whole organism in conditions of reduced gravity. Such knowledge is essential in order to make space travel and residence on the moon or Mars practicable. Reproduction among highly differentiated organisms such as mammals, birds, and other vertebrates and probably also invertebrates will obviously be seriously affected by the absence of gravity (cf. Guyenne, 1990). Organisms with large amounts of yolk in their eggs, such as amphibians and birds, will be seriously affected by the redistribution of components within the egg when gravity is greatly reduced. Homolecithal eggs, such as those of human beings, would probably be less affected, but even in these eggs, the molecular and organellar traffic would surely be affected by the prolonged absence of gravity. The basic hereditary organelle of the cell, the chromosome, and the many molecules with which it interacts to produce precise patterns of gene activity during development and in normal adult physiological function would also be influenced by gravity (Figure 2). Can such animals and plants reproduce on a space platform and through several successive generations? Only research on the station could answer these questions. Moreover, we do not now have the insights required to ask many questions that will surely become obvious by experience in space. Stable long term experiments through several generations are needed on a space station in order to know our capabilities and to protect them for the long trips to Mars or residence on the moon or Mars. Once we develop a clear understanding of the consequences of the absence of gravity on our physiological and developmental capacities, such information will also enlighten our response to challenges here on Earth. In fact, such information and understanding would be of great value even if we never ventured into space.

In summary, there are two major reasons for building a space station and carrying on long-term experiments in biological and biomedical sciences on that platform. First, we must do so if we are to keep human beings and other organisms in space or on other planets, the moon, or Mars for extended periods of time. We cannot survive there under present circumstances, and we do not know enough to overcome the hostile environments due to the absence of gravity and to the various other challenges of space, such as radiation (McCormack et al., 1989). Second, we will achieve deeper insight into the nature of our own biological structures and activities by understanding the significance of gravity in the development of morphology and physiological function (cf. e.g., Oser and Battrick, 1989). We cannot predict what the research on organisms in the absence of gravity will produce. Otherwise, we would not need to do the research. But that there will be significant enlightenment seems obvious. Surprises there will be, and we should be enthusiastic in welcoming the knowledge and insights that will surely result from biomedical research in space.

REFERENCES

Alberts, B., Bray, D., Lewis, J., Raff, M., Roberts, K., and Watson, J.D. 1989. *Molecular Biology of the Cell*, Second Edition. New York: Garland Publishing.

Asashima, M. and Malacinski, G.M. (Eds.) 1990. *Fundamentals of Space Biology*. Tokyo/Berlin: Japan Scientific Societies Press/Springer-Verlag, 203 p.

Avers, C. 1989. *Process & Pattern in Evolution*. New York: Oxford University Press.

Boveri, T. 1910. Ueber die Teilung centrifugierter Eier von *Ascaris megalocephala*. *Archiv der Entwicklungsmechanik und Organismen* 30: 101-125.

Briggs, D.E.G. and Crowther, P.R. (Eds.) 1990. *Paleobiology: A Synthesis*. Oxford: Blackwell.

Garshnek, V. 1988. Soviet space flight: The human element. *ASGSB Bulletin* 1: 67-80.

Guyenne, T.D. (Ed.) 1990. *Microgravity as a Tool in Developmental Biology*. Paris: European Space Agency. (ESA SP-1123) (ISBN 92-9092-064-5)

Halstead, T.W., Todd, P., and Powers, J.V. (Eds.) 1991. Gravity and the Cell: Report of a Conference Held December 1-3, 1988 in Washington, D.C. *ASGSB Bulletin* 4(2): 1-260.

Krikorian, A.D. and Levine, H.G. 1991. Development and growth in space, Chapter 8. In: *Plant Physiology: A Treatise*, Vol. X (Bidwell, R.G.S., Ed.). Orlando, FL: Academic Press, p. 491-555.

McCormack, P.E., Swenberg, C.E., and Buecker, H. (Eds.) 1989. *Terrestrial and Space Radiation and its Biological Effects*. NATO Advanced Study Institute

Series A. Life Sciences. 154. Corfu, Greece, 11-25 October 1988. New York: Plenum.

Murtha, M.T., Leckman, J.F., and Ruddle, F.H. 1991. Detection of homeobox genes in development and evolution. *Proceedings of the National Academy of Sciences, USA* 88: 10711-10715.

Oser, H. and Battrick, B. (Eds.) 1989. *Life Sciences Research in Space*. Paris: European Space Agency, 141 p. (ESA SP-1105) (ISSN 0379-6566)

Robbins Committee Report. 1988. *Exploring the Living Universe: A Strategy for Space Life Sciences. A Report of the NASA Life Sciences Strategic Planning Study Committee*. Washington, DC: NASA, 231 p.

Schopf, J.W. (Ed.) 1983. *Earth's Earliest Biosphere. Its Origin and Evolution*. Princeton, NJ: Princeton University Press, 543 p.

Souza, K.A. and Halstead, T.W. (Eds.) 1985. *NASA Developmental Biology Workshop*, Arlington, Virginia, May 1984. Moffett Field, CA: NASA, Ames Research Center, 92 p. (NASA TM-86756)

Stebbins, G.L. 1982. *Darwin to DNA, Molecules to Humanity*. San Francisco, CA: W.H. Freeman.

REPORT DOCUMENTATION PAGE		Form Approved OMB No. 0704-0188
1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE October 1993	3. REPORT TYPE AND DATES COVERED Technical Memorandum
4. TITLE AND SUBTITLE Space Life Sciences Research: The Importance of Long-Term Space Experiments		5. FUNDING NUMBERS
6. AUTHOR(S)		
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Science Communication Studies, George Washington Univ. Washington, DC 20006 and NASA Office of Life and Microgravity Sciences and Applications Washington, DC 20546		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) National Aeronautics and Space Administration Washington, DC 20546		10. SPONSORING/MONITORING AGENCY REPORT NUMBER NASA TM-4502
11. SUPPLEMENTARY NOTES		
12a. DISTRIBUTION/AVAILABILITY STATEMENT Unclassified - Unlimited Subject Category - 51		12b. DISTRIBUTION CODE

13. ABSTRACT *(maximum 200 words)*

This report focuses on the scientific importance of long-term space experiments for the advancement of biological science and the benefit of humankind. It includes a collection of papers that explore the scientific potential provided by the capability to manipulate organisms by removing Earth's gravity, the force that has been instrumental in the evolution and development of all organisms. It discusses the scientific justification for why the long-term space exposure that can be provided by a space station is necessary to conduct significant research. Early research results, limited as they have been, show numerous scientific benefits to humankind resulting from life science research conducted in space.

14. SUBJECT TERMS			15. NUMBER OF PAGES
life sciences, aerospace medicine, space stations, reduced gravity, gravitational physiology, biological effects, physiological effects, plants, animals, human beings, cells, space flight			48
			16. PRICE CODE A03
17. SECURITY CLASSIFICATION OF REPORT UNCLASS	18. SECURITY CLASSIFICATION OF THIS PAGE UNCLASS	19. SECURITY CLASSIFICATION OF ABSTRACT UNCLASS	20. LIMITATION OF ABSTRACT UNLIMITED

Available from NASA Center for AeroSpace Information
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